NASA Environmentally Responsible Aviation's
Highly-Loaded Front Block Compressor Demonstration

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High OPR Compressor Demonstration

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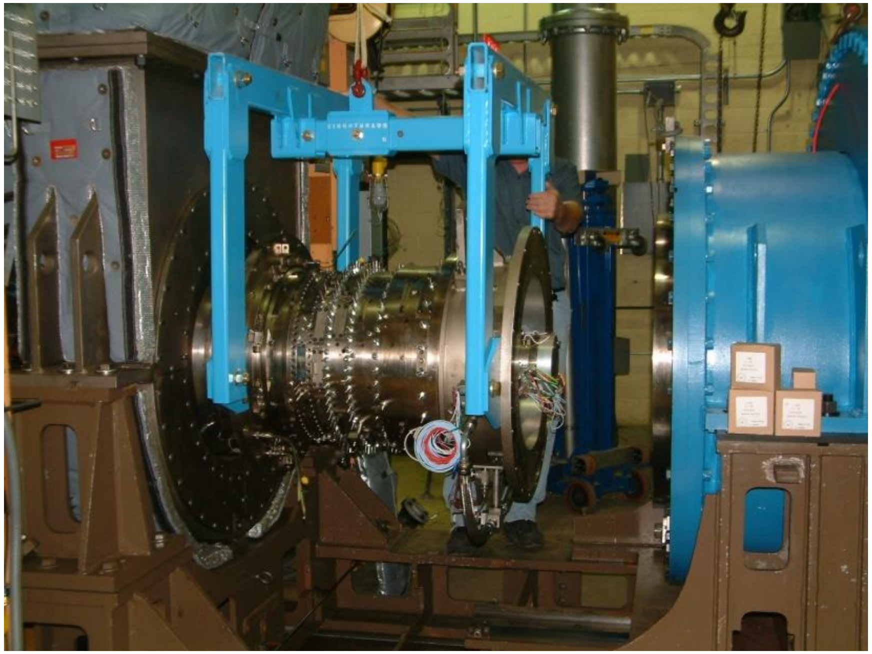
Outline

- Thermal Efficiency Improvement Through Higher OPR
- Mgmt by Tech Challenge
- W7 Test Facility
- Phase I Test Setup
- Phase 1 Summary
- Phase 2 Plan
- Phase 2 Results



- Additional Efficiency Improvements Through CMC applications
- Summary/Closing Remarks

Management by Technical Challenge

TFA3: Advanced UHB Engine Designs for Specific Fuel Consumption and Noise reduction

TC3 – Demonstrate UHB efficiency improvements to achieve 15% TSFC reduction, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while reducing engine system noise and minimizing weight, drag, NOx and integration penalties at AC system level

Need

Increased engine system overall pressure ratio (OPR) for reduced fuel consumption while reducing engine system noise and minimizing weight, drag, NOx, and integration penalties at the aircraft system level

Goal

Demonstrate front block compressor technologies to enable high pressure ratio (30:1) core compressors for a 2-3% reduction in SFC (specific fuel consumption)

Success Criteria

- Minimum Success – Test & document the performance (PR and Efficiency) and operability (Stall Margin) of the first 3 stages of a 30:1 PR class high pressure compressor (HPC)
- Full Success – Minimum success plus demonstrate performance improvements (in PR and/or Efficiency) of the first 3 stages of a 30:1 PR class HPC while maintaining operability

Objectives

- Design and test a three-stage front block, 30:1 class HPC to meet minimum efficiency and operability requirements
- Design and test an improved front block that shows higher pressure ratio at a constant efficiency while meeting the same operability requirements
- Validate design methodology against experimental measurements
- Measure the performance (pressure ratio and temperature ratio vs. mass flow) of a three-stage front block of a HPC design
- Validate required operability with increased stall margin and improved aeromechanic response

KPP2025 & TRL

- Reduce TSFC by 2.5%
- TRL 3 to 5

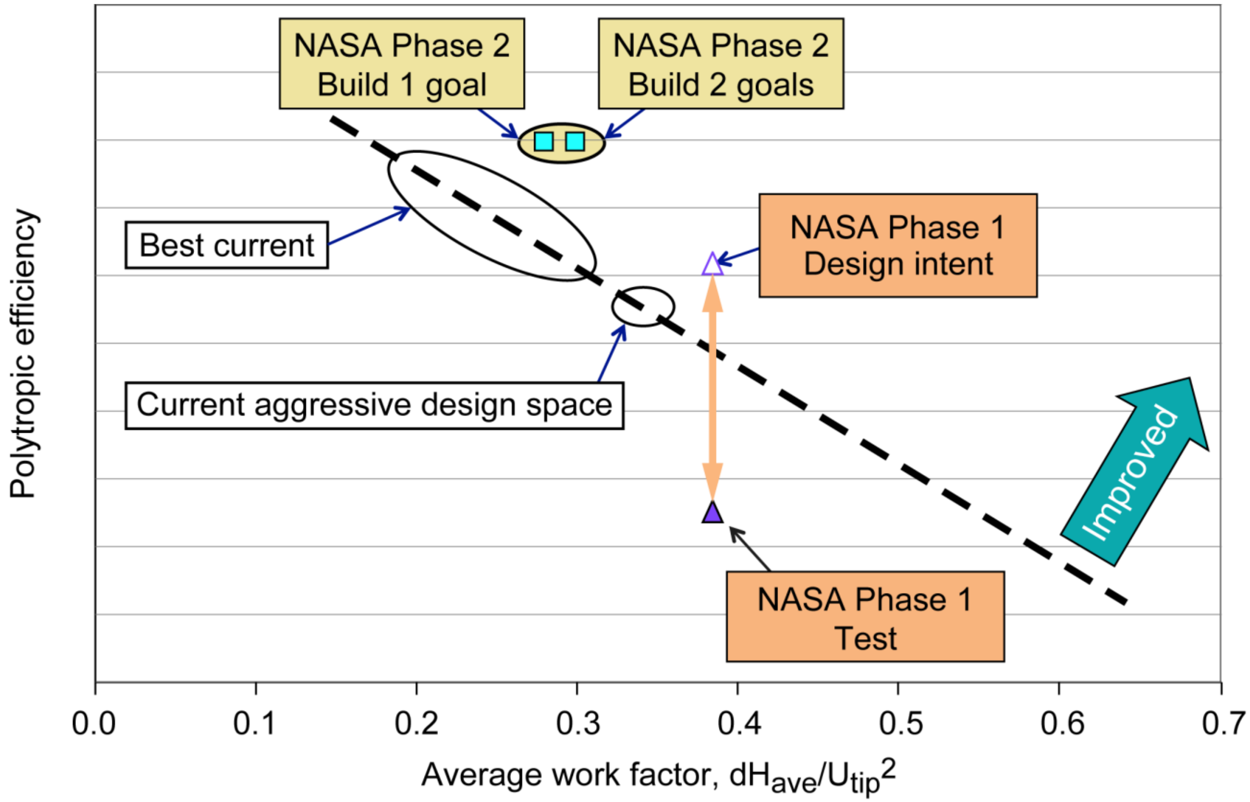
Key Deliverables

- HPC front block performance and operability data for baseline and advanced configurations
- Compressor map data delivered to systems analysis team
- Technology maturation report

Applicability

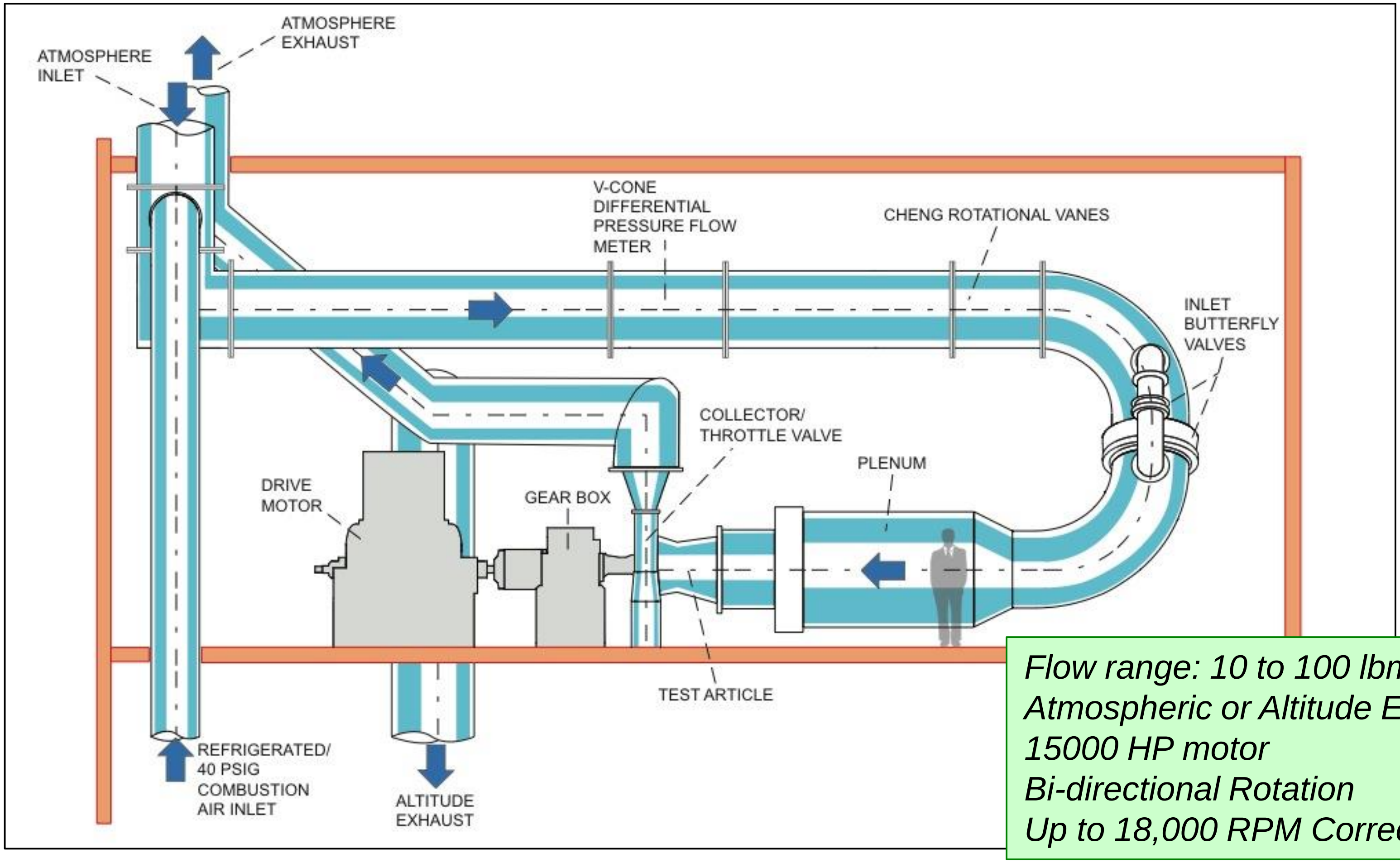
- High-power density, high thermal efficiency cores that enable UHB systems
- Scalable across all current, advanced and unconventional aircraft configurations and size classes

ITD 30A
Highly Loaded Front Block Compressor



Phase 2 Goals were Achieved Based on Leveraging Phase 1 Understanding.

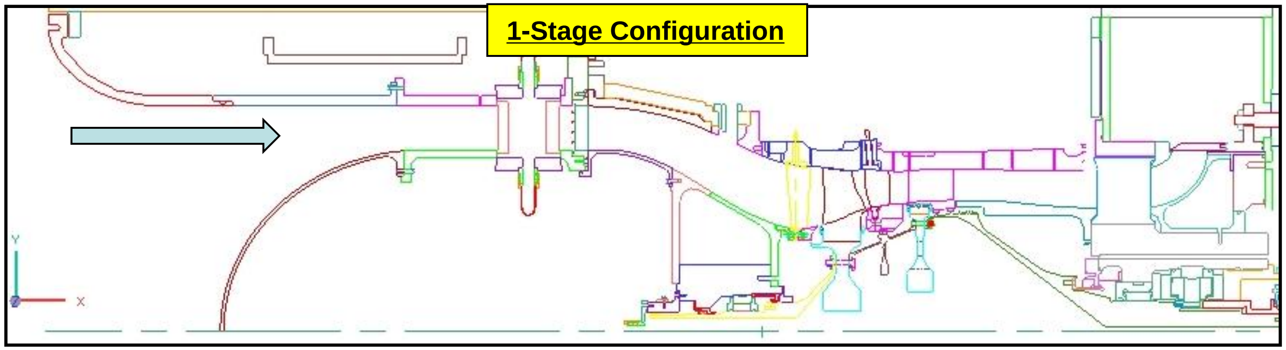
Test Facility – NASA GRC W7 Multistage Test Cell



Flow range: 10 to 100 lbm/sec
Atmospheric or Altitude Exhaust
15000 HP motor
Bi-directional Rotation
Up to 18,000 RPM Corrected

Upgrades Made to W7 for Flow Quality & Mass Flow Measurement Accuracy

Phase 1 Test Setup



Phase 1 Blading Design

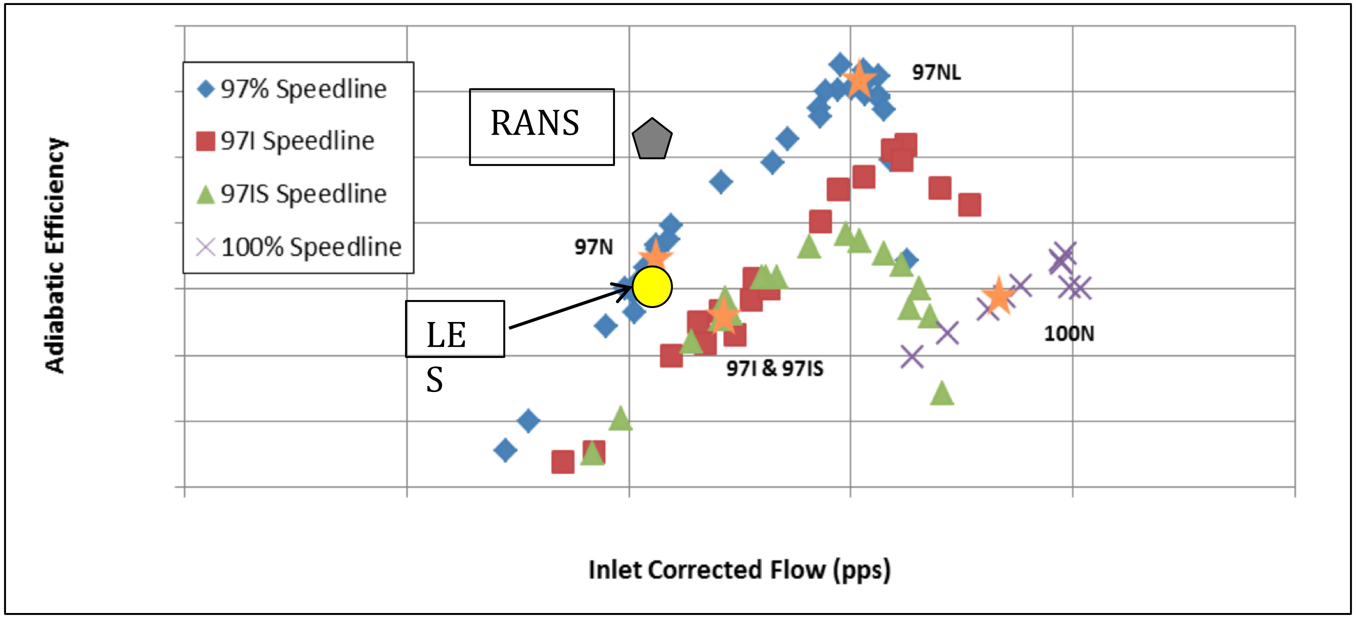
Legacy hardware/Aggressive design
Rotors supersonic from root to tip
Low efficiency not captured by CFD

Challenge: Understand Phase 1 front block aerodynamic loss mechanisms

- ✓ Designed an experiment to uncouple a 1-stage and 2-stage configuration to unravel the source of efficiency loss in highly loaded compressors
- ✓ Generate a high quality data set to perform post-test data matching and CFD analysis to try and analytically predict the measured loss and inefficiency

Purpose: Understand high stage loading HPC front stage loss mechanisms

Phase 1 Summary

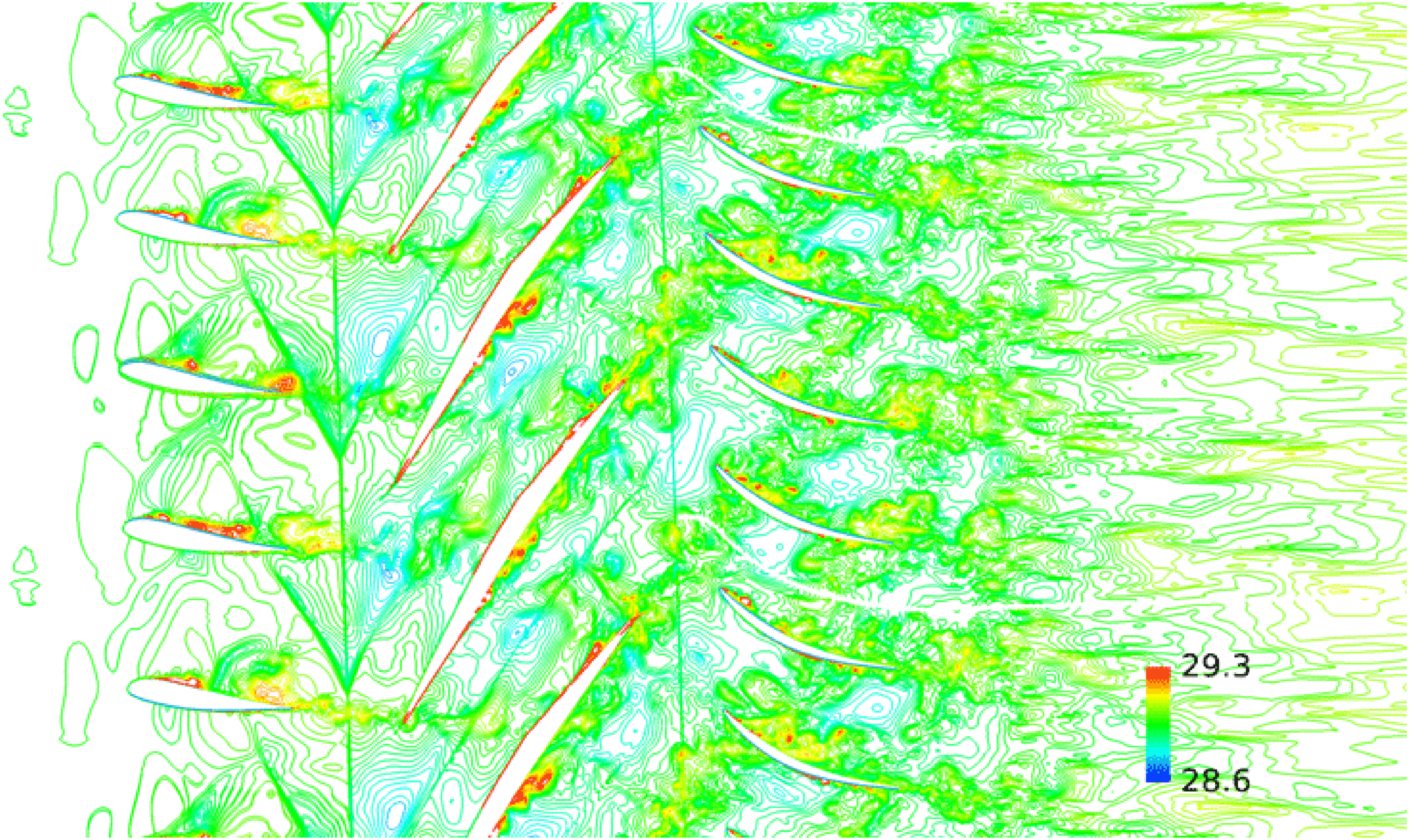


- Analysis shows the loss source is isolated to within the single stage configuration
- RANS CFD (steady and unsteady) doesn't seem to capture the measured losses
- Initial LES results show promise to capture the loss source

✓ **Continue to post-process the detailed data and compare to CFD simulations**

✓ **Run LES without IGV to isolate the loss source**

IGV/Rotor/Stator Simulation (NASA LES Code)
Entropy generation at mid-span



Phase 2 Plan

Minimum Success: Demonstrate front block compressor technologies to enable HP core compressors for a 2-3% reduction in SFC

Build1 = Baseline

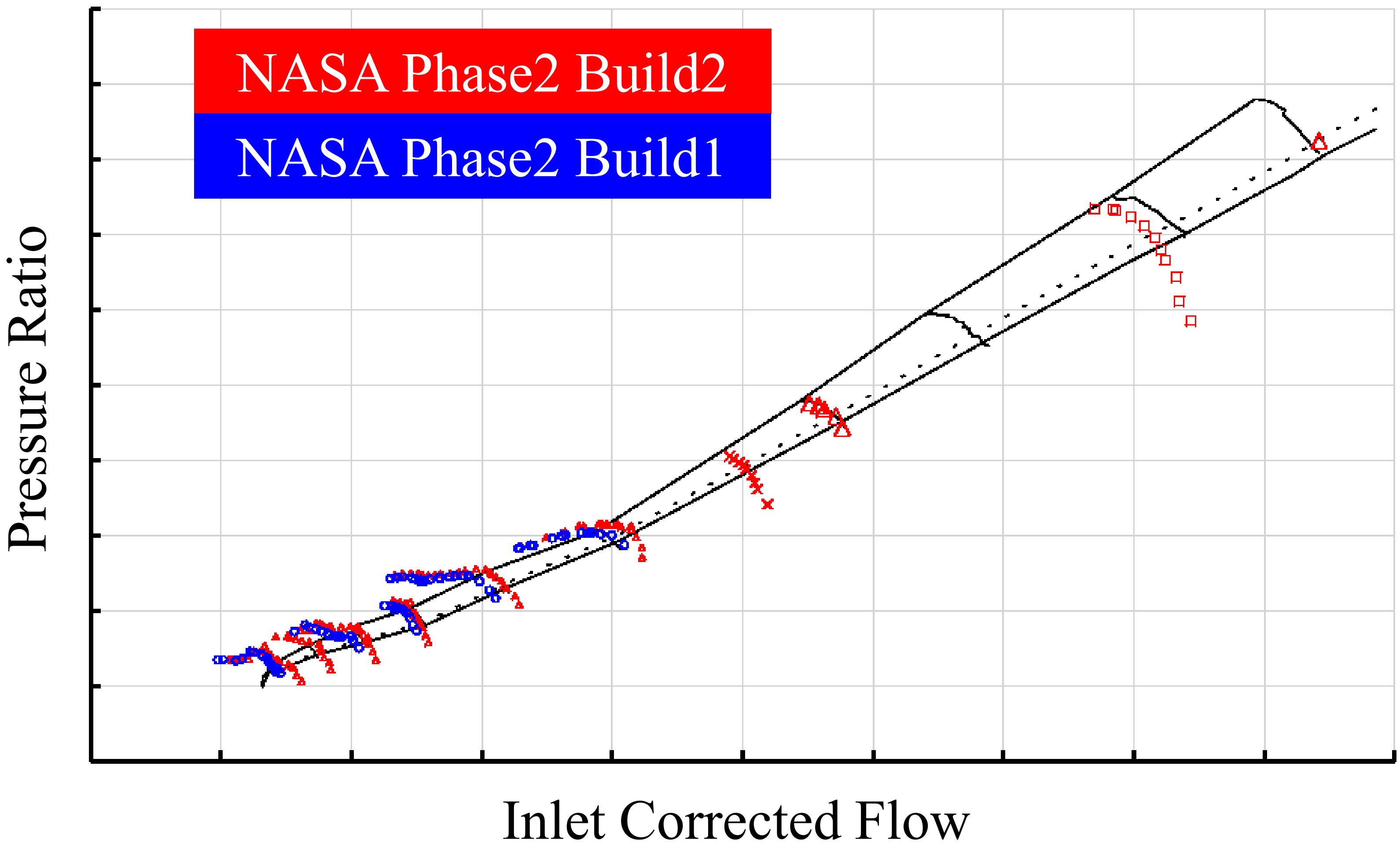
Full Success: Min Success + demonstrate a performance improvements in PR and/or Efficiency while maintaining operability

Build2 = Redesigned Blades

Baseline Installed in W7

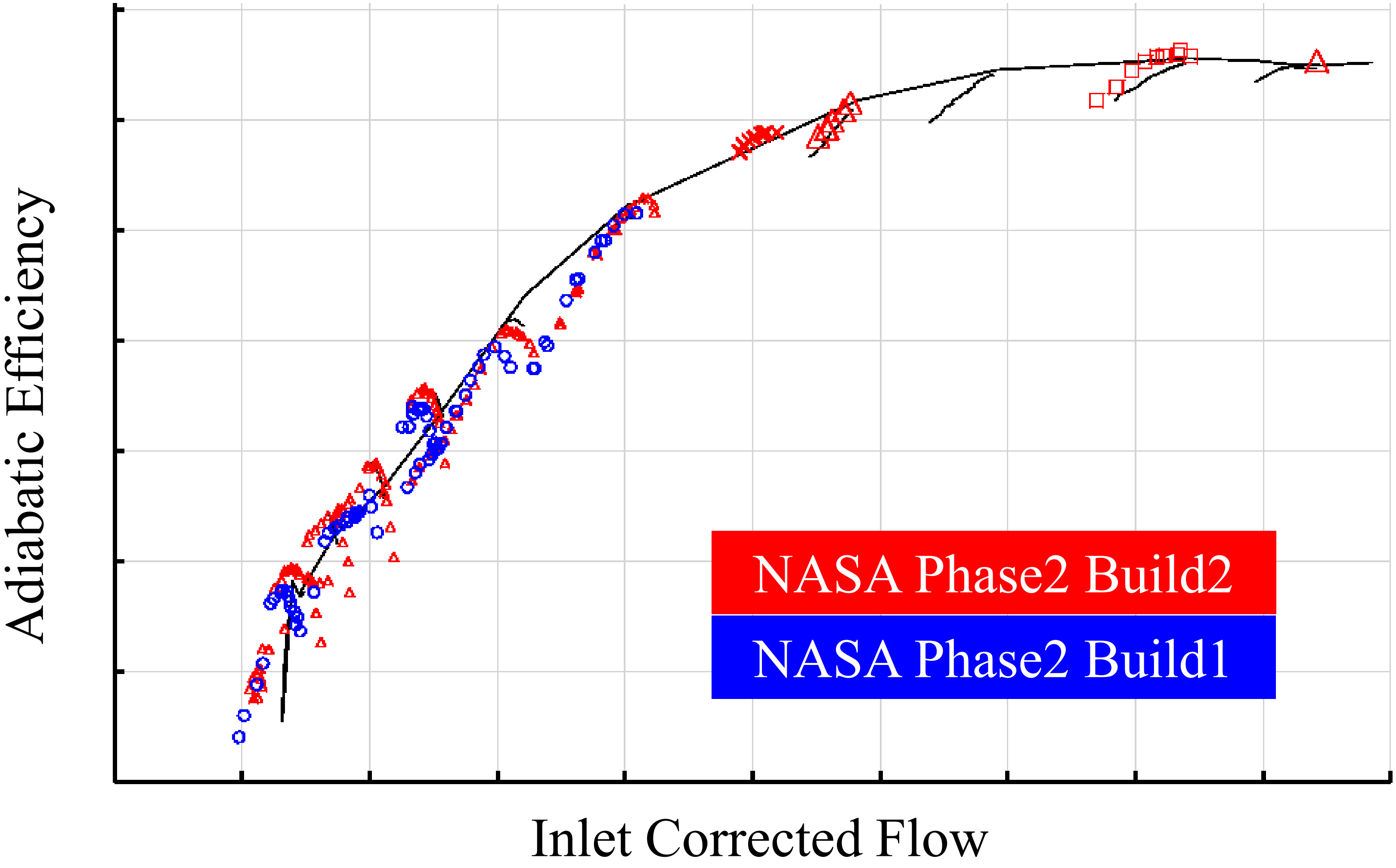
Full success achieved as was the goal of 2.5% TSFC reduction for the technology.

PR vs. Inlet Corrected Flow



- Build 1 hardware defects prevented full speed operation
- Build 2 fully successful by capitalizing lessons learned from Build 1

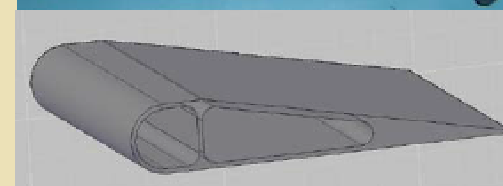
Ad. Eff. vs. Inlet Corrected Flow

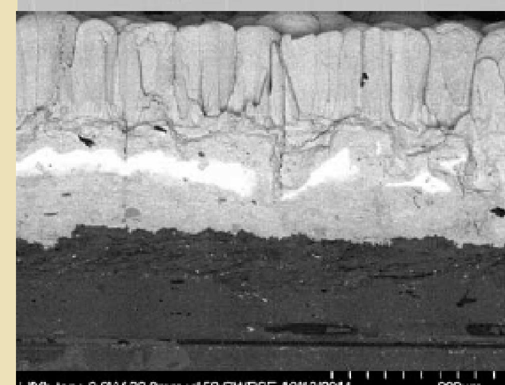


Goal: 2.5% TSFC Reduction Achieved: 2.94% TSFC Reduction

Additional Efficiency Improvements through CMC Applications

Four technologies focused on the evaluation of commercially available CMCs, Sub-component fabrication and testing, and EBC development and testing.





1. **SiC/SiC CMC Combustor Liner:**
   - 2700ºF* (1482ºC) temp. capability and less cooling (~60%)

   => more efficient combustion and reduced NOx (~30-40%)

   * The EBC raises the SiC/SiC CMC component temperature capability from 2400ºF (1316ºC) to 2700ºF (1482ºC)

2. **SiC/SiC CMC Turbine Vane**
   - 2700ºF* (1482ºC) temperature capability

   => reduced fuel burn (~3-6%)

3. **Environmental Barrier Coatings (EBC) for CMCs**
   - Provides a thermal barrier and environmental stability for the combustor liner and vane components

   => temperature capability 2700ºF (1482ºC)

4. **Oxide/Oxide CMC Exhaust Nozzle**
   - reduced weight (~20%) and improved mixing efficiency

   => reduced fuel burn

Subscale & Full Scale CMC Oxide/Oxide Nozzle demonstrated under ERA for upcoming Rolls-Royce Engine Test

Summary & Closing Remarks

- ERA investment in W7 successful in mitigating test risks. Provides unique and versatile facility for SOA multistage compressors and experienced personnel to execute future test campaigns.
  - Phase 1 Lessons Learned Implemented as Phase 2 Risk Mitigation
    - Speed control worked well
    - Cross-talk eliminated between inlet and exhaust
    - Oil leaks eliminated from Phase 1 testing
- Min & Full Success Criteria Met despite cascading issues related to fabrication slips / schedule slips / assembly issues.
- Propulsion Technology Accomplishments
  - ✓ TRL 5 demonstration of highly-loaded front block compressor technology.
  - ✓ Achieved Full Success (demo of a Baseline and PIP compressors)
  - ✓ Exceeded TSFC Reduction Goals
- Phase II built on Phase I: Leveraging Integrated Technology Development / Demonstration coupled with systems analysis and incorporation of Advanced Vehicle Concepts
- CMC Applications under ERA being demonstrated in upcoming RR test